

REPORT

Studies of the Hot Gas in the Galactic halo and Local Bubble

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OVERVIEW

I plan to move from Johns Hopkins University to the University of Georgia this autumn. Before moving, I would like to report the progress that I have made on “Studies of the Hot Gas in the Galactic halo and Local Bubble” while at JHU.

The broad goals of this project are to determine the physical conditions and history of the hot phase of the Galaxy’s interstellar medium. Such gas resides in the Galactic halo, the Local Bubble surrounding the solar neighborhood, other bubbles, and supernova remnants. A better understanding of the hot gas and the processes occurring within it requires several types of work, including ultraviolet and X-ray data analyses and computer modeling.

HIGHLIGHTS

One of the most important species for studies of hot gas is the O VI ion. O VI traces $\sim 300,000$ K gas and, in theory, traces the transition zone between hotter, X-ray emitting gas and cooler gas. When this award began, the emission from the Galaxy’s interstellar O VI (1032, 1038 Å) had been measured for only a few lines of sight, and only one of these measurements was of high quality. Early in the award period, I analyzed a second, comparatively high quality O VI emission dataset (item 1). With this data, I more tightly constrained the estimated properties and distribution of the Galaxy’s hot gas. The results suggest that most of the O VI resonance line emission comes from relatively shallow layers

of hot gas in the Galactic halo. The O VI sampled along this direction appears to reside in quiescently recombining gas (item 2), while the O VI observed in the first high quality observation seems to have been heated more recently (item 3).

In order to measure the fractions of the observed emission which originate in the Galactic halo and Local Bubble, respectively, I proposed for a set of very long “shadowing” observations. In the first observation, *FUSE* was pointed toward an opaque cloud between the Local Bubble and the halo. Only emission from the Local Bubble surrounding the solar neighborhood would be observable in this observation. This work set a tight constraint on the Local Bubble’s O VI resonance line emission, which was used to evaluate theories for the Local Bubble (item 4). Before I performed this project, two major theories vied to explain the Local Bubble. This project eliminated one of the theories and tightly constrained the other. Furthermore, the results show that transition zones contain much less O VI than theoretically expected. The paucity of O VI in transition zones is corroborated by Bill Oegerle’s, Ed Jenkins’s, David Bowen’s, Pierre Chayer’s, and my search for O VI *column density* within the Local Bubble (item 5). Item 6 discusses how these new findings are affecting our understanding of the fundamental astrophysics of hot plasmas.

The second part of the shadowing observation was to observe a nearby, off-cloud direction. My colleagues, Shauna Sallmen, Jeff Kruk, and Ed Jenkins, and I have done this. We are in the process of analyzing the data. Another colleague, K. D. Kuntz, and I are analyzing the *XMM* data for the same on-cloud and off-cloud directions. Because the X-ray signals will be very weak, we must perform an extremely detailed analysis of the instrumental background. We have partially completed this analysis.

The physical processes that shape, cool, and disrupt hot gas are also in need of study. In order to understand the actions of thermal conduction, cloud evaporation, and ejecta mixing, K.D. Kuntz, Rob Petre, and I analyzed the *Chandra* observations of an older

supernova remnant (W44). This project yielded a pleasant surprise – for the first time, the data showed how the ejecta enhanced the abundances in the center of an older supernova remnant. (Previous work on ejecta had focussed on young remnants and found ejecta near their peripheries.) Not only do the observations indicate how extensively gas mixes within the remnant, but they contribute to the explanation for why older remnants have X-ray bright centers. By making computer simulations of a thermally conductive SNR of W44's age and size and comparing with the *Chandra* observation, I showed that thermal conduction may be taking place within W44 and modifying W44's internal structure to make its center denser and thus brighter. By making similar computer simulations and comparisons, I was able to show that significant cloudlet evaporation within the remnant is incompatible with the observation (items 7, 8). As a result of this work (which has been supported primarily by a *Chandra* grant) and the O VI emission upper limit for the Local Bubble, we can say that we cannot find any evidence for evaporation of clouds in the interstellar medium. This is a crucial piece of information, because such evaporation, if it were to exist (see McKee & Ostriker, 1977), would control the energy balance in the $\sim 300,000$ K hot interstellar medium. In addition, our data on the supernova remnant included enough counts from the pulsar nebula for a scientifically useful analysis. Those results were published separately (item 9).

During this period, my efforts to simulate possible heating scenarios have concentrated on supernova remnants. Several detailed hydrodynamic and spectral simulations have been performed. They add weight and detail to previous suggestions that supernova remnants above the Galactic H I disk are important sources of hot gas. In the future, I plan to more fully determine the effects of various parameters by performing several more simulations.

ADDITIONAL WORK

I also worked with Jayant Murthy, Dick Henry, and Jay Holberg in interpreting the O VI intensity upper limits imposed by *Voyager* (item 10) and with Barry Welsh, Shauna Sallmen, Daphne Sfeir, and Rosine Lallement in interpreting their *FUSE* O VI data for high latitude sight-lines (item 11). More recently, I have been working with B.-G. Andersson, David Knauth, Steve Snowden, and Peter Wannier on the relationship between O VI and soft X-ray emitting gas (item 12).

PUBLICATIONS

1. Shelton, R. L. 2002, "Observations of O VI Emission from the Diffuse Interstellar Medium Toward $\ell = 113^\circ, b = 71^\circ$ ", *ApJ*, 2002, *ApJ*, 569, 758-765
2. Shelton, R. L. 2002, "O VI Resonance Line Emission from the Galactic Interstellar Medium", 2002, in "Proceedings for the XVIIth Institute for Astrophysics in Paris Conference on Gaseous Matter in Galaxies and Intergalactic Space", ed. Ferlet, R., Lemoine, M., Desert, J.-M., and Raban, B., p. 105-108
3. Shelton, R. L., Kruk, J. W., Murphy, E. M., Andersson, B.-G., Blair, W. P., Dixon, W. V., Edelstein, L., Fullerton, A. W., Gay, C., Hawk, J. C., Jenkins, E. B., Linsky, J. L., Moos, H. W., Oegerle, W. R., Oey, M. S., Roth, K. C., Sahnou, D. J., Sankrit, R., Savage, B. D., Sembach, K. R., Shull, J. M., Siegmund, O. H. W., Vidal-Madjar, A., Welsh, B. Y., & York, D. G. "Observations of O VI Emission from the Diffuse Interstellar Medium", 2001, *The Astrophysical Journal*, 560: 730-741
4. Shelton, R. L. 2002, "Surprisingly Little O VI Emission Arises in the Local Bubble", 2003, *ApJ*, 589, 261-269
5. Oegerle, W. R., Jenkins, E. B., Shelton, R. L., Bowen, D. L., and Chayer, P., "A Survey of O VI Absorption in the Local Interstellar Medium", in preparation

6. Shelton, R. L., "The Local Bubble: How Can Models Account for the Paucity of $\sim 300,000$ K Gas?", proceedings for "How Does the Galaxy Work, A Galactic Tertulia with Don Cox and Ron Reynolds", 2003, in preparation
7. Shelton, R. L., Kuntz, K. D. & Petre, R. 2001, "*Chandra* Observations of the Mixed Morphology Supernova Remnant W44", BAAS, 199.12607
8. Shelton, R. L., Kuntz, K. D., and Petre, R., "*Chandra* Observations of the Mixed Morphology Supernova Remnant, W44", ApJ, submitted
9. Petre, R., Kuntz, K. D., and Shelton, R. L. "The X-Ray Structure and Spectrum of the Pulsar Wind Nebula Surrounding PSR B1853+01 in W44", 2002, ApJ, 579, 404-410
10. Murthy, J., Henry, R. C., Shelton, R. L. & Holberg, J. B. "Upper Limits on O VI Emission from Voyager Observations", 2001, ApJ, 557, L47-L50
11. Welsh, B. Y., Sallmen, S., Sfeir, D., and Shelton, R. L., and Lallement, R., "Far Ultraviolet Spectroscopic Explorer (FUSE) observations of emitting and absorbing gas in the Local Interstellar Chimney", 2002, A & A, 394, 691-699
12. Andersson, B.-G, Knauth, D. C., Snowden, S. L., Shelton, R. L., and Wannier, P. G., "A Hot Envelope Around the Southern Coalsack, X-ray and FUV Observations", 2003, ApJ, submitted